Original Article

Prevalence of Hematoma Expansion and Signs in Non-contrast Computed Tomography for Predicting Hematoma Expansion in Spontaneous Intracerebral Hemorrhage at Siriraj Hospital

Dittapong Songsaeng*, Sirirat Yuyod, Sittaya Buathong, Kullathorn Thephamongkhol, Wassana Peuksiripibul, Sastrawut Thammakittiphan

Abstract

Introduction: Hematoma expansion (HE) in intracerebral hemorrhage (ICH), defined by a volume increase of more than 33% or 6 ml, often leads to poor outcomes and mortality. This study aims to examine non-contrast computed tomography (NCCT) indicators for HE prediction and their associations with patient clinical data and HE occurrence.

Methods: We retrospectively analyzed data and measured HE using image analysis software in NCCT images including initial and follow-up scan at < 7 days from 169 patients during Jan 2013 - Aug 2019 at Siriraj Hospital.

Results: HE was found in 44 of the 169 patients with spontaneous ICH (26%), occurring in two periods: at 10-25 h (peak at 7 h) and at 50-75 h (peak at 50 h). Atrial Fibrillation (AF) and anticoagulant use were more prevalent in the HE group (15.9% and 20.5%) compared to the non-HE group (4.8% and 7.2%, p = 0.042 and p = 0.022). HE was associated with an increase in mortality at 60-day and 90-day (29% and 32.3%, p = 0.016 and p = 0.010) and a decrease in the time to follow-up scan (median = 21 h and 48 h). Satellite sign, heterogeneous density, intra-hematoma hypodensity, and fluid level prevalence were 46.2%, 35.5%, 21.9%, and 4.1%, but only heterogeneous density and intra-hematoma hypodensity were significantly associated with HE (p = 0.003 and p = 0.011), with heterogeneous density being an independent predictor (OR, 2.4; 95% CI, 1.2-5.1, p = 0.019) according to logistic regression analysis.

Conclusions: Heterogeneous density in NCCT is found to be an independent predictor of HE among other significant HE-associated findings, which included heterogeneous density, intra-hematoma hypodensity, and various clinical data. Two peaks in expansion activity related to HE development were observed, a novel finding in this study, emphasizes the importance of delayed follow-up NCCT.

Keywords: Hematoma expansion, Prediction Sign, NCCT HE predictors, Spontaneous ICH

Volume 24, Issue 3, Page 44-54

https://asianmedjam.com

Received: 2 November 2023 **Revised: 4 July 2024** **Accepted: 4 July 2024**

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Introduction

Stroke is one of the leading cause of death and long-term disability. The prevalence of stroke in Thailand is estimated to be 1.88% among adults older than 45 years. The major risk factors for stroke are hypertension, diabetes, dyslipidemia, metabolic syndrome, and atrial fibrillation (AF). Stroke can be divided into 2 types: ischemic stroke and hemorrhagic stroke. Hemorrhagic stroke represents about 20% of all stroke cases.[1]

All patients admitted to a hospital with suspected acute stroke should receive a brain imaging evaluation upon arrival at the hospital. In most cases, non-contrast computed tomography (NCCT) is performed and provides the necessary information to help make the decision about acute management.[2]

The overall fatality of intracerebral hemorrhage case at 1 month is approximately 40%.[3] In spontaneous intracerebral hemorrhage (ICH), the incidence of any hematoma expansion (HE) occurrence is 73%, while a significant expansion (> 33%) occurs in 38% of cases. HE has been associated with an increase in mortality.[4]

HE is defined as an increase in intraparenchymal hematoma volume observed on the follow-up scan of more than 33% or 6 ml from the baseline hematoma volume.[5, 7]

The computed tomographic angiography (CTA) spot sign is not widely used, although it is a strong and validated radiological marker for HE.[8] NCCT is more widely applied for the diagnosis of ICH rather than CTA. Several NCCT markers of HE have been reported, such as an irregular shape, heterogeneous density, blend sign, intra-hematoma hypodensity, swirl sign, island sign, satellite sign, and hematoma sedimentation level or fluid level.[6-7, 9-11]

Many studies highlight the varying prevalence and degree of association of these NCCT markers with HE. The presence of a satellite sign, where a small hematoma separates from the main hematoma, is associated with worse outcomes in ICH patients.[9] The island sign, characterized by three or more small hematomas adjacent to the main hematoma or four or more partially connected bubble-like hematomas, is found in 8.8% of ICH patients and is associated with hematoma expansion (HE) (11.4%, $p = 0.001$).[7] A heterogeneous density, defined by a Barras score of ≥ 3,[10] is also associated with HE (40.3%, $p < 0.001$)[6] with sensitivity, specificity, PPV, and NPV of 44%, 72%, 40%, and 76%, respectively.[11] Intra-hematoma hypodensity, blend sign, and swirl sign, all indicating a hypodense area with an indistinct margin, are significantly associated with HE, occurring in 23%-40% of cases.[6, 7, 12] The hematoma sedimentation or fluid level is also associated with HE with 15% sensitivity, 94% specificity, 50% PPV, and 73% NPV.[11] Further study of these NCCT signs and parameters should help us gain more understanding about hematoma expansion and improve its prediction.

Moreover, at many hospitals in Thailand, such as at Siriraj Hospital, most of the patients with spontaneous ICH who receive conservative treatment have a follow-up NCCT scan when the patient shows clinical deterioration. Accurate prediction is necessary in clinical settings. By using CT imageanalysis software to determine the hematoma volume, providing more accurate data and decreasing variability between reads this study aims to investigate the potential of NCCT parameters, including the satellite sign, heterogeneous density, intra-hematoma hypodensity, and fluid level sign, for predicting HE in spontaneous ICH patients, and their associations with patient clinical data and HE occurrence.

Methods

This study was approved by the Institutional Review Board (IRB) of Siriraj Hospital (COA no. Si 663/2019). We retrospectively reviewed 1547 cases recorded in the Siriraj Hospital ICH database between January 2013 and August 2019. The inclusion criteria were: (1) age ≥ 18 years old; (2) spontaneous ICH confirmed by CT scan at Siriraj Hospital; (3) onset-to-CT time < 12 h; and (4) follow-up CT scan performed within 168 h or 7 days after initial CT scan. The exclusion criteria were: (1) secondary ICH, such as hemorrhagic transformation from a cerebral infarct, cerebrovascular anomalies, tumor, and trauma; (2) unavailable baseline CT or follow-up CT; and (3) surgical evacuation before the follow-up CT scan. 169 patients were eligible for the study after applying the inclusion and exclusion criteria (Figure 1).

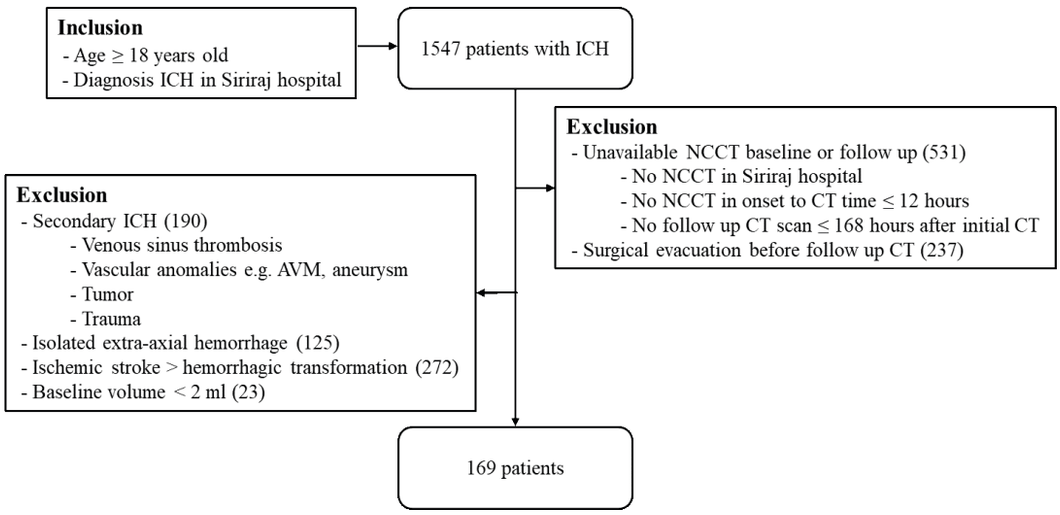


Figure 1 Flowchart of the patients' participation in the study

The following baseline information was collected from 169 patients with spontaneous ICH: demographic variables (age and gender), medical history [hypertension (HT), diabetes mellitus (DM), atrial fibrillation (AF), and hematologic disease], medication use (antiplatelet and anticoagulant), admission Glasgow Coma Scale (GCS) score, admission blood pressure levels [systolic blood pressure (SBP) and diastolic blood pressure (DBP)], and laboratory data [platelet count, prothrombin time (PT), and activated partial thromboplastin time (aPTT)].

Two reviewers analyzed the scans together: a third-year resident and a radiologist. Any disagreements between them were resolved by consensus.

Imaging technique

The CT scans (120 kVp; 200-490 mA; section thickness, 1.25 mm; pitch, 1:1) were performed on 64-slice CT scanners (GE Lightspeed VCT, GE Discovery, General Electric, USA), and a 256-MDCT system (GE revolution CT, General Electric, USA).

Image analysis

ICH was diagnosed, based on the CT density profile and the Hounsfield unit (HU), by using axial images of 1.25-mm thick section obtained from a routine protocol brain CT scan. The location of the ICH was classified into 4 areas: lobar (cortex and subcortical white matter), deep (basal ganglia, thalamus, internal capsule, and deep periventricular white matter), brainstem, and cerebellum. When the hemorrhage was of large volume and spread to more than 2 areas, the location of the ICH was defined based on the area of the main hemorrhage.

The onset-to-CT time and the duration between the initial CT and the follow-up CT were also recorded.

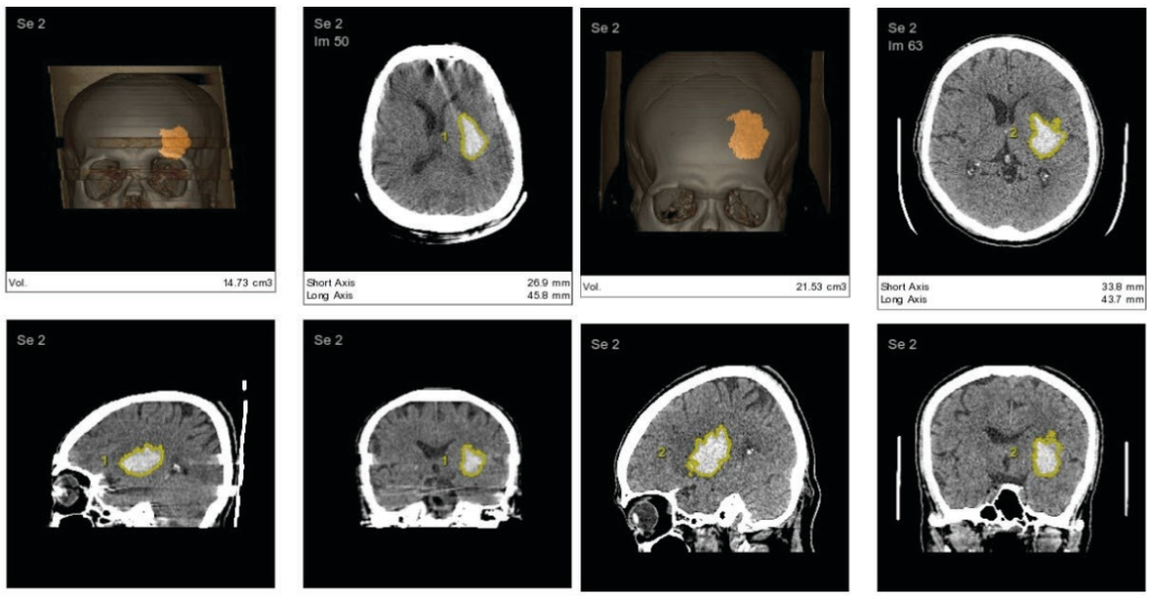
Measurement of the main hemorrhage size

Hematoma volumes were measured using Stroke VCAR, a CT image analysis software with a semi-automated function. After user initiation, it automates segmentation of regions of interest (ROIs) suspected of hematoma, allowing manual correction if necessary. Hemorrhagic lesions undetectable by software can be manually traced, and the total volume was calculated by summing ROIs across slices. The software's accuracy is approximately 85% for intra-cerebral hematomas (Stroke VCAR User Guide Direction 5486219-1EN, Revision 3). Intraventricular hemorrhage, subarachnoid hemorrhage, and small hemorrhages were excluded from the measurements. Patients with hematoma volume under 2 ml on initial CT were also excluded due to software limitations.

Outcomes

Hematoma expansion

Using the image analysis software to provide the quantitative results (ml and percentage change), HE was defined as an increased hematoma size by more than 6 ml or 33%[5, 7] as shown in Figure 2.



*Cumulative Volume

Exam Time	Cumulative Volume
Apr 05 2019 04:03:23	21.53 cm3 (+46%)(+6.80 cm3)
Apr 04 2019 22:10:31 (Reference)	14.73 cm3

Figure 2 An example of calculated hematoma volume: from initial (left) and follow-up CT scan (right) measured by Stroke VCAR software.

Satellite sign

The criteria for the satellite sign in NCCT were: (1) a small hematoma completely separate from the main hematoma in at least one slice; (2) the largest transverse diameter of the small hematoma <10 mm; and (3) a minimal distance from the small hematoma to the main hematoma of between 1 and 20 mm.[3] If the satellite sign was questionable in the axial images, the coronal and sagittal reformatted images were also evaluated for more precise results.

Heterogeneous density

Christen D. Barras et al. (2009)[10] defined a 1 to 5 heterogeneous density scale in a pioneering article, in which 1 represented a homogeneous hemorrhage and 5 a heterogeneous hemorrhage. In this study, heterogeneous density was defined as 3 to 5 points on the 5-point scale, as shown in Figure 3.

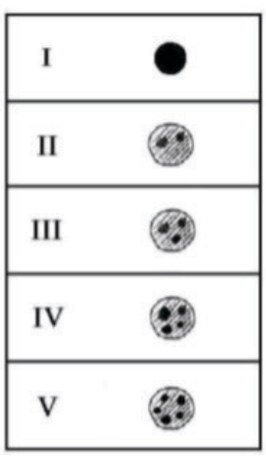


Figure 3 Categorized heterogeneous density scales

Intra-hematoma hypodensity

Intra-hematoma hypodensity was defined as hypodensity foci within the hematoma which have no connection to the surface of the hematoma.

Fluid level

Fluid-blood level (also known as the blood sedimentation level).[11]

Statistical analysis

Baseline characteristics of the HE and non-HE groups were compared. Parametric data are shown as mean ± standard deviation and significant differences between groups are assessed using the student t-test. Non-parametric data are presented as median with interquartile range and significant differences between groups are assessed using the Mann−Whitney U test. Categorical data using the chi-square. Multivariable logistic regression, using significant factors ($p < 0.05$) from univariate analysis, determined the adjusted OR and 95% CI for non-contrast CT signs. Statistical significance was established at $p < 0.05$. Analyses were performed using SPSS 16.0 and Excel 2013.

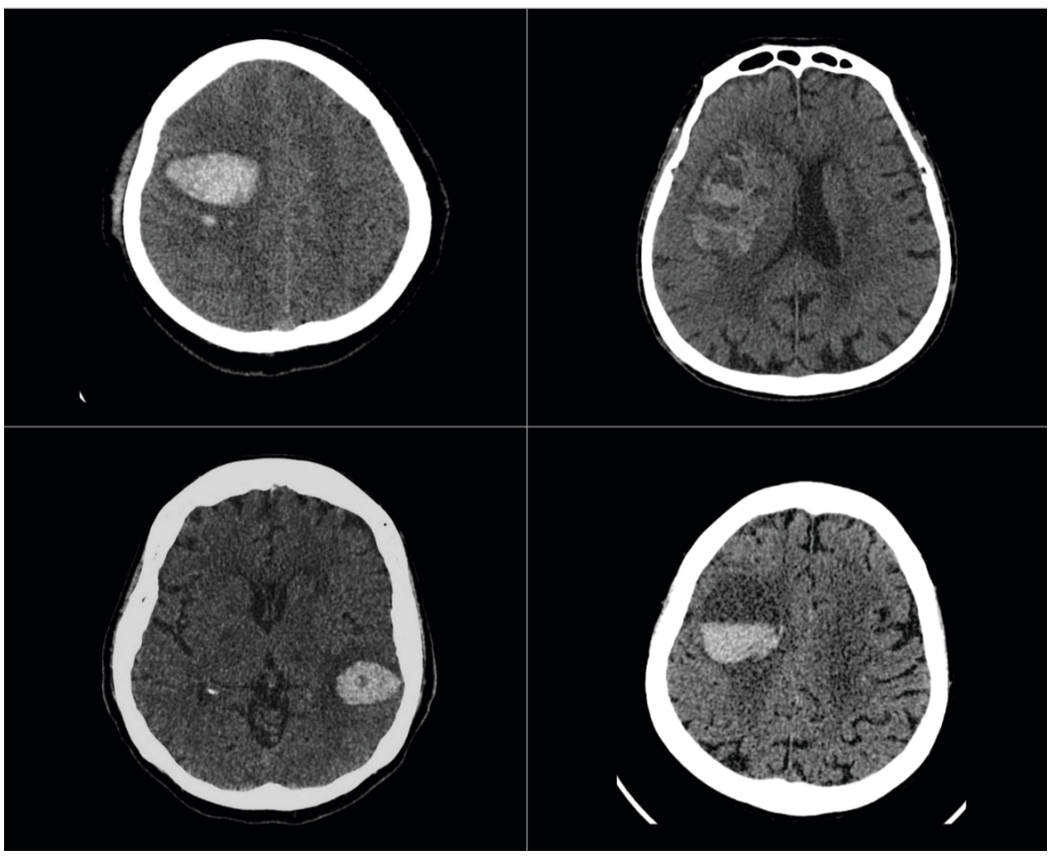


Figure 4 Examples of reported NCCT markers for HE. A, satellite sign. B, heterogeneous density. C, intra-hematoma hypodensity. D, fluid level.

Results

After application of the eligibility criteria, 169 of the 1547 patients with spontaneous intracerebral hemorrhage were included in the analysis (Figure 1), comprising 105 male and 64 female patients. The mean age was 62 years. The median times to the initial CT scan and follow-up CT scan were 3 h (range, 1 to 12 h) and 41 h (range, 1 to 168 h). ICH was located in the lobar, deep, brain stem, cerebellum, and intraventricular hemorrhage (IVH) in 42 (24.9%), 116 (68.6%), 9 (5.3%), 2 (1.2%), and 82 (48.5%) patients, respectively. The median initial ICH volume was 18.3 ml (range, 2.1 to 87.1 ml) and the median follow-up ICH volume was 27.0 ml (range, 0.3 to 133.0 ml).

The baseline characteristics were comparable between the HE and non-HE groups (Table 1). Age, sex, GCS, DBP, HT, DM, hematologic disease,

antiplatelet use, platelet count, PT, aPTT, time to initial CT scan, and location of the ICH of the HE and non-HE groups were similar. Any HE was found in 93 (55%) cases. Significant HE according to the criterion of an increased hematoma size by more than 33% or 6 ml was found in 44 (26%) cases. The mean systolic blood pressure (SBP) was higher in the non-HE group compared to the HE group, which had means of 176 vs. 163 mmHg. AF was found significantly more often in the HE group than in the non-HE group (15.9% vs. 4.8%, $p = 0.042$). Significantly more patients with anticoagulant use were found in the HE group (20.5% vs. 7.2%, $p = 0.022$). The time to the initial CT scan was similar between the two groups (median, 3 h; range, 1-12 h). The time to the follow-up CT scan was different between the two groups, with a median of 21 h in the HE group and 48 h in the non-HE group.

Table 1 Univariable analysis comparing the HE group with the non-HE group.

Variable	All	HE	Non-HE	*P*-value
Patients	169	44 (26.0%)	125 (74.0%)	
Age (year)	61.6 (14.0)	62.8 (16.8)	61.1 (13.0)	0.564
Sex (male)	105 (62.1%)	27 (61.4%)	78 (62.4%)	1.000
GCS (/15)	15 (3-15)	13 (6-15)	15 (3-15)	0.176
SBP (mmHg)	172.9 (35.6)	163.0 (36.9)	176.4 (34.7)	0.032
DBP (mmHg)	98.9 (22.2)	93.3 (22.8)	100.8 (21.7)	0.053
Hypertension	96 (56.8%)	22 (50.0%)	74 (59.2%)	0.376
DM	39 (23.1%)	6 (13.6%)	33 (26.4%)	0.098
AF	13 (7.7%)	7(15.9%)	6 (4.8%)	0.042
Hematologic disease	7 (4.1%)	3 (6.8%)	4 (3.2%)	0.378
Antiplatelet use	32 (18.9%)	9 (20.5%)	23 (18.4%)	0.824
Anticoagulant use	18 (10.7%)	9 (20.5%)	9 (7.2%)	0.022
Platelet count ($x10^3$/ul)	236.3 (89.1)	220.0 (101.1)	242.1 (84.1)	0.157
PT (seconds)	14.1 (9.0)	16.4 (13.2)	13.4 (6.9)	0.150
aPTT (seconds)	26.3 (7.3)	28.1 (8.3)	25.6 (6.8)	0.076
Time to initial CT (h)	3 (1-12)	3 (1-12)	3 (1-12)	0.450
Time to follow-up CT (h)	41 (1-168)	21 (2-168)	48 (1-168)	0.000
Location				
- Lobar	42 (24.9%)	13 (29.5%)	29 (23.2%)	
- Deep	116 (68.6%)	28 (63.6%)	88 (70.4%)	
- Brain stem	9 (5.3%)	1 (2.3%)	8 (6.4%)	
- Cerebellum	2 (1.2%)	2 (4.5%)	0 (0%)	
P-value				**0.058**
IVH	82 (48.5%)	16 (36.4%)	66 (52.8%)	0.079
Initial ICH volume (median)	18.3 (2.1-87.1)	25.2 (2.6-59.3)	16.0 (2.1-87.1)	0.184
Follow-up ICH volume (median)	19.9 (0.3-133.0)	41.5 (3.7-133.0)	14.6 (0.3-92.6)	0.000
Satellite sign	78 (46.2%)	26 (59.1%)	52 (41.6%)	0.054
Heterogeneous	60 (35.5%)	24 (54.5%)	36 (28.8%)	0.003

Table 1 Univariable analysis comparing the HE group with the non-HE group. (cont.)

Variable	All	HE	Non-HE	*P*-value
Intra-hematoma hypodensity	37 (21.9%)	16 (36.4%)	21 (16.8%)	0.011
Fluid level	7 (4.1%)	4 (9.1%)	3 (2.4%)	0.076
30-day mortality	18 (11.8%)	8 (20.0%)	10 (8.8%)	0.084
60-day mortality	19 (14.3%)	9 (29.0%)	10 (9.8%)	0.016
90-day mortality	21 (16.0%)	10 (32.3%)	11 (11.0%)	0.010

Abbreviations: GCS = Glasgow coma scale; SBP = systolic blood pressure; DBP = diastolic blood pressure; DM = diabetes mellitus; AF = atrial fibrillation; PT = prothrombin time; aPTT = activated partial thromboplastin time; IVH = intraventricular hemorrhage; ICH = intracerebral hemorrhage.

The prevalence of the satellite sign, heterogeneous density, intra-hematoma hypodensity, and fluid level was 46.2%, 35.5%, 21.9%, and 4.1%, respectively. The heterogeneous density was significantly associated with the HE group (54.5%, $p = 0.003$). Intra-hematoma hypodensity was also significantly associated with the HE group (36.4%, $p = 0.011$). The satellite sign and the fluid level were not significantly different between the two groups. Multivariable logistic regression modeling, as shown in Table 2, suggested that heterogeneous density was an independent predictor of HE (OR, 2.4; 95% CI, 1.2-5.1, $p = 0.019$). Heterogeneous density had a sensitivity of 54.5%, specificity of 71.2%, PPV of 40.0%, and NPV of 81.7%.

Table 2 Multivariable analysis comparing the HE group with the non-HE group.

Variable	OR	95% CI	*P*-value
AF	2.419	0.211-27.770	0.478
Anticoagulant use	0.910	0.095-8.742	0.935
Satellite	1.499	0.699-3.211	0.298
Heterogeneous density	2.443	1.159-5.149	0.019
Intra-hematoma hypodensity	1.991	0.819-4.841	0.129
Fluid level	2.984	0.419-21.258	0.275

Abbreviations: CI = Confidence Interval; AF = Atrial Fibrillation.

HE had higher mortality in 30 days, 60 days, and 90 days and was significantly associated with 60-day and 90-day mortality (29% in 60-day, $p = 0.016$; 32.3% in 90-day, $p = 0.010$. Five patients who expired after 30 days were diagnosed with hospital-acquired pneumonia (HAP, 3 patients) or sepsis (2 patients).

The association between the expansion volume and the time to follow-up CT scan is shown by the graph in Figure 5. We found that HE occurred in two periods of follow-up time; the first expansion at about 10-25 h (peak 7 h) and the second expansion at about 50-75 h (peak 50 h).

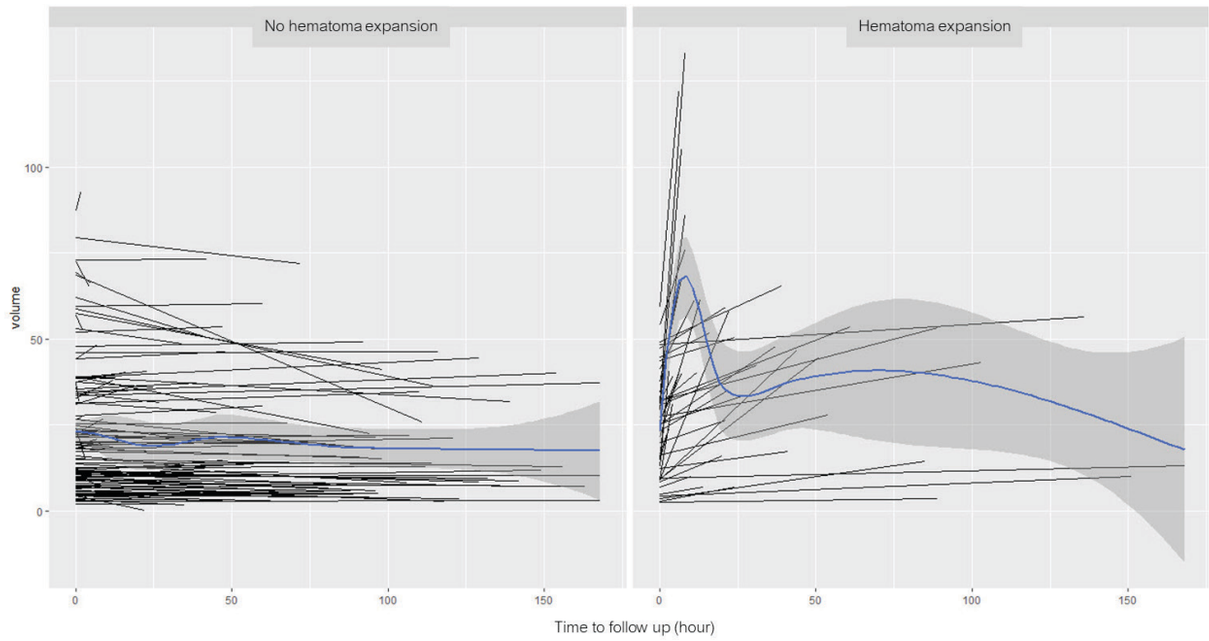


Figure 5 The association between the expansion volume and the time to follow-up CT scan

Discussion

HE was found in 44 of 169 study patients (26.0%). Despite certain limitations due to varying follow-up times, the prevalence of HE in this study was very close to that reported in a previous study by Law Z. et al., using the same criteria, which found an HE prevalence of 27.4%.[7] However, the prevalence can vary from 13%-38% when using other criteria.[4, 6, 8-12]

Like many previous studies in which HE was associated with 90-day mortality and poor clinical outcome, our study found a significant association between HE and 60-day and 90-day mortality.[4, 6] According to patient clinical data, we found that SBP, underlying AF, and anticoagulant use were significantly associated with HE. The SBP was higher in the non-HE group compared to the HE group, with means of 176 and 163 mmHg respectively. This result is intriguing as it suggests that while intensive lowering of systolic blood pressure to < 140 mmHg is generally expected to prevent hematoma growth, this is not apparent in our study. Two recent randomized trials, INTERACT-2 and ATACH-2, showed non-significant trends toward reduced hematoma enlargement with intensive blood pressure control.[14] We also found that patients with underlying atrial fibrillation (AF) and anticoagulant use were associated with HE, which contradicts previous studies that reported no such association.[6, 7, 9] Most patients with underlying AF use anticoagulant therapy to prevent stroke. This can cause coagulopathy with an increased tendency to develop spontaneous intracranial hemorrhage, and the possibility of hematoma expansion. Other characteristic data, including age, sex, GCS, HT, DM, hematologic disease, and antiplatelet use, were not associated with HE. Laboratory data, platelet count, PT, and aPTT were not associated with HE in our results. These results correspond to the results of most previous studies.[4-12]

The time to the initial CT scan was similar between HE group and non-HE group, and was 3 h (range, 1-12 h). This result was similar to the figures reported in two previous studies by S.M. Davis [4] and D. Dowlatshahi,[5] but different from other studies with a time from onset to conducting NCCT of less than 2.5 h (OR, 3.73; 95% CI, 1.9-7.5, $p < 0.001$).[6]

The time to follow-up CT scan was significantly shorter in the HE group, with a median time of 21 h in the HE group and 48 h in the non-HE group. However, the patterns of the expansion curve were similar between the two groups in which HE occurred in two periods of follow-up time; the first expansion was at about 10-25 h (peak 7 h) and the second expansion was at about 50-75 h (peak 50 h). Christian Ovesen et al. reported that HE occurred within 6 h after administration of the scan, which

resembled our study.[13] These results are new and imply that a follow-up CT scan 24 h after the initial CT scan still has benefit for determining hematoma expansion, since HE is known to be critical and requires careful management.

In our study, other baseline data, such as the time to initial CT scan, baseline hematoma volume, and hematoma location, were not associated with HE, at either peak of HE. To the contrary, Andrea Morotti et al. found that a time to initial CT scan of less than 2.5 h from onset was related to HE[6] and the onset to the CT scan time was slightly shorter in their HE group, which showed a median of 1.8 (1.3-2.5) h in the HE group and 2.0 (1.4-3.0) h in the non-HE group.[7] Regarding the baseline hematoma volume, we found that it was inconclusive. The prior results vary, with some studies associating smaller hematomas with HE,[6] while others link larger hematomas to HE.[7] The location of the hematoma and intraventricular hemorrhage were not significantly associated with HE, which is similar to most previous studies.[4, 6, 7, 9, 12]

Our results revealed that a heterogeneous density and intra-hematoma hypodensity in NCCT were significantly associated with HE. These results were similar to the previous study by Andrea Morotti et al.[6] Multivariate analyses revealed that only a heterogeneous density was significantly associated with HE (OR, 2.4; 95% CI, 1.2-5.1, $p = 0.019$). The heterogeneous density had a sensitivity of 54.5%, specificity of 71.2%, PPV of 40.0%, and NPV of 81.7%. These results agree with and correspond to those of Andrea Morottio et al. which stated that a heterogeneous density was associated with HE (40.3%, $p < 0.00.1$),[6] and by Dylan Blacquiere et al. who reported a sensitivity of 44%, specificity of 72%, positive predictive value (PPV) of 40%, and negative predictive value (NPV) of 76%.[11] In addition, a meta-analysis performed by Danfeng Zhang et al. (2018) concluded that a heterogeneous density was associated with HE (OR, 5.17; 95% CI, 3.72-7.19, $p < 0.001$), poor functional outcome (OR, 3.60; 95% CI, 1.98-6.54, $p < 0.001$), and mortality (OR, 4.64; 95% CI, 2.96-7.27, $p < 0.001$).[15] The pathophysiology of a heterogeneous density may be described by the phase of the hemorrhage. Liquid blood tends to hypo-attenuate on NCCT, whereas clotted blood shows higher attenuation.[16] Together, these represent an active hemorrhage and its possible progression.

Although the satellite sign and fluid level were more commonly found in the hematoma expansion group, these signs were not significantly associated with hematoma expansion. A previous study from Siriraj Hospital showed that the finding of the satellite sign was significantly higher in patients with HE (any expansion; 57.8%, $p = 0.02$) and was an independent predictor of HE (OR, 2.50; 95% CI, 1.16-5.35, $p = 0.019$).[17] However, the satellite sign was not significantly associated with substantial HE (> 33%).[17] By using the same criteria, our results for the satellite sign agree with those of the previous study at Siriraj Hospital.[17] Dylan Blacquiere et al. reported that the hematoma sedimentation level or fluid level was associated with HE.[11] We did not see this association, however the low prevalence of fluid level (7 out of 169 patients (4.1%) in our results) may have affected the statistical analyses.

One of the limitations of this study was only using the standard definition of hematoma expansion (≥ 6 mL or ≥ 33%), instead of using the revised definition that includes new IVH development or expansion (≥ 6 mL or ≥ 33% or any IVH; ≥ 6 mL or ≥ 33% or IVH expansion ≥ 1 mL).[18] The revised definition was published at the time when we ended our study. The disadvantage of the standard definition is less sensitivity and generally a poorer prediction of 90-day outcomes compared to the revised definition.[18] However, we included IVH as a factor in this study, which did not show a significant association between IVH and HE. This is consistent with other studies that marked IVH as a dependent factor for poor outcome.[19-21] Further studies using the revised definition should have a more accurate representation of outcomes. Recent studies using the revised criteria still show that there is no single highly sensitive and specific NCCT marker for the prediction of revised hematoma expansion.[22] Further study of this issue could also provide significant information. According to our study, heterogeneous density in NCCT is an independent predictor of HE, which is an established predictor of poor prognosis in ICH patients. Heterogeneous density and intra-hematoma hypodensity were significantly associated with HE in our study group. HE was significantly associated with underlying AF, anticoagulant use, time to follow-up CT scan, and 60-day and 90-day mortality. In this

study, two peaks in expansion activity related to the development of HE were found, which recommends the performing of follow-up NCCT after a delay in time. From our conclusions, recognizing these signs, significant clinical data, and the nature of the two peak expansion could hopefully be beneficial for Thai medical practitioners in improving ICH management including the detection of high-risk, HE patients as well as the administering of more active preventive treatment.

Acknowledgments
Financial support: None reported.

Compliance with Ethics Requirements: All processes performed in studies involving human participants were in accordance with the ethical standards of Siriraj Institutional Review Board.

Conflict of interest: All authors report no conflicts of interest relevant to this article.

Acknowledgments: We gratefully acknowledge the support from the Department of Radiology, Faculty of Medicine, Siriraj Hospital, Mahidol University for providing patient information and CT scan images.

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